Progress of NOAA Great Lakes Environmental Research Laboratory Based on Recommendations from the 2010 Laboratory Science Review

This document provides a summary of GLERL's progress in addressing the recommendations from the 2010 Science Review Panel. The 2010 GLERL Science Review Summary Report, submitted by the Science Review Panel, and the GLERL response to the report are located here: http://www.glerl.noaa.gov/review2016/reviewer_documents.html

The overarching recommendation from the *2010 GLERL Science Review Summary Report* was to develop "a cohesive strategic plan for the entire lab so the vision and future goals become clear and appropriate metrics can be developed to determine progress and inform management decisions." In response to this recommendation, GLERL developed the *NOAA Great Lakes Environmental Research Laboratory Strategic Plan 2012: Innovative Research for the Freshwater Seas*. The 2012 strategic plan included a new mission statement, along with a vision statement that highlights the global lake and marine impacts of GLERL research as they extend beyond the regional impacts on the Great Lakes basin. Further work on this recommendation was addressed in 2015, with the development over several months of the document, *NOAA Great Lakes Environmental Research Laboratory Strategic Plan 2016-2020: A Commitment to Integrated Scientific Research in the Great Lakes and Coastal Ecosystems.* The laboratory's 2016-2020 strategic plan was developed with adherence to guidance provided by OAR's Policy Planning and Evaluation (PPE). Also noteworthy is the high level of staff engagement in the development of the strategic plan that facilitated consensus building for the plan among GLERL staff, both at the Ann Arbor facility and the Lake Michigan Field Station.

Response to Recommendations

1. Develop bold, integrated, strategic plans with 1, 5, and 10-year milestones for individual research areas and GLERL as a whole.

- The 2012 Strategic Plan outlined a bold new vision for the laboratory and included short-term milestones and long-term goals.
- In 2013, short-term and mid-term tasks and actions required to reach these milestones were also incorporated into a GLERL Annual Operating Plan with continued production of annual operating plans each year.
- In 2015, GLERL drafted a new laboratory Strategic Plan for 2016-2020, which continues to guide the organization in advancing its mission.

2. Address staff issues through targeted additions in mission critical areas

GLERL recognizes the need for targeted staff additions to carry out its new mission and vision.
The 2012 Strategic Plan listed four priority staff additions in mission-critical areas needed to help meet specific science objectives. The following four positions have been filled.

- Observing System & Advanced Technology Branch Lead: Steve Ruberg
- Harmful Algal Bloom / Phytoplankton Ecologist: Tim Davis
- Benthic Ecologist: Ashley Baldridge

- Integrated Physical and Ecological Modeling and Forecasting Lead: Philip Chu

In addition, nine more staff members have been hired; six of whom were replacements for employees who retired or left service

- Physical scientist / hydrodynamic modeler: Eric Anderson
- IT Specialist: Travis Nester
- General Engineer: Kyle Beadle
- IT Specialist Lead: Brad Sagowitz
- Editor: Nicole Rice
- Deputy Director: Jennifer Day (Acting) with a newly appointed permanent Deputy Director expected to start in spring 2016.
- Director: Deborah Lee Director
- Office Automation Assistant: Mike Ryan
- Communications Specialist: Margaret Lansing

GLERL rewarded promotions to seven deserving staff members—a key to retaining in-house expertise: Steve Constant, Duane Gossiaux, Jim Liebig, George Leshkevich, Steve Pothoven, Mike Ryan, Jia Wang.

During this time span GLERL lost 15 employees to retirement or other positions:
John Bratton, Julie Dyble Bressie, Marie Colton, Cathy Darnell, Gary Fahnenstiel, John Fenton, Nathan Hawley, Tom Joyce, John Lane, Stephen Lozano, Giselle Maira, Glenn Muhr, Thomas Nalepa, David Schwab, Mike Taetsch.

Relationships with recent retirees have been maintained through emeritus and visiting scientist arrangements: Ray Assel, Nathan Hawley, Tom Nalepa, David Schwab.

As we expect numerous retirements in the next few years, GLERL has developed a new staffing plan and a process for assessing unexpected hiring needs to maintain continuity and build expertise in critical areas. The staffing plan can be viewed in the Succession Plan Appendix document posted on the review web site: http://www.glerl.noaa.gov/review2016/

3. Increase collaboration with the Cooperative Institute for Limnology and Ecosystems Research (CILER), U.S. Geological Survey (USGS), and industry (through the Small Business Innovation Research program) to maximize funding and fiscal efficiency.

Collaboration with the Cooperative Institute for Limnology and Ecosystems Research (CILER):
GLERL and CILER significantly increased collaborative interactions between 2010 and 2015.

- **Leadership Activities:**
  - GLERL leadership facilitated a face-to-face meeting in the summer of 2011 between CILER and University of Michigan administrators and the NOAA Administrator, Dr. Jane Lubchenco, which resulted in commitments that significantly strengthen the NOAA-CILER partnership.
  - GLERL Laboratory managers and senior scientists actively participated in development of the new CILER strategic plan in 2011, and serve as key members of the CILER Executive Board, Management Council, and the new CILER Council of Fellows.

- GLERL has coordinated with and supported the CILER director in strengthening the involvement of additional academic institutions in addition to the University of Michigan to increase connectivity throughout the Great Lakes region.
- GLERL Leadership hosted Marie Lynn Miranda, Dean of the University of Michigan School of Natural Resources and Environment for strategic discussion
- Leadership visits by Craig McLean (NOAA Office of Atmospheric and Oceanic Research), Rick Spinrad (NOAA), and Louis Uccellini (National Weather Service) which included meetings with CILER staff.

- **Research Activities**: Collaboration with CILER is vital to many GLERL science priorities. In FY16, CILER is involved in 16 of 25 GLERL base projects, and five of eight external projects in which GLERL is involved. CILER staff comprise approximately 30 percent of the research and communications staff at the Ann Arbor facility. There are currently twenty-five CILER science and communications staff co-located with forty-one federal and thirteen contract staff at GLERL's Ann Arbor facility.

  Examples of co-located CILER expertise essential to GLERL research projects:
  - Nutrient measurements (CILER support scientist)
  - Autonomous underwater vehicle expertise (two CILER support staff)
  - Ice-Lake coupled processes (CILER Research Fellow)
  - Biophysical Modeling (CILER Postdoctoral Research Fellow)
  - Beach water quality monitoring, HABs team (CILER Research Lab Specialist Associate)
  - Web-based visualization tools (CILER programmer/analyst)

  Examples of CILER collaborations with University of Michigan Academic Departments that enhance GLERL's connectivity to the University of Michigan:
  - Ayumi Manome (CILER Research Fellow) with University of Michigan Department Civil & Environmental Engineering, and Climate & Space Sciences and Engineering)
  - Ed Rutherford (GLERL PI) and Hongyan Zang (CILER): Impact of Asian Carp on Great Lakes Foodweb
  - Tim Davis, Steve Ruberg (GLERL PIs) with Tom Johengen (CILER): Synthesis Observation and Response research project
  - Eric Anderson (GLERL PI) with Dima Beletsky and Raisa Beletsky (CILER): Lake Circulation and Great Lakes Forecasting System: Can HRRR meteorological forcing conditions be used to improve hydrodynamic forecasting skill?
  - Drew Gronewold (GLERL PI) with Joeseph Smith (CILER) Monitoring, Understanding, and Forecasting Over-lake Evaporation
  - Jia Wang (GLERL PI) with Mark Rowe (CILER) Lake-scale physical/biological modeling (FVCOM-NPZD Model with River Loading in Lake Michigan

- **Great Lakes Seminar Series:** Since the 2010, CILER and GLERL have coordinated to develop the Great Lakes Seminar / Webinar Series. This series brings in regional, national, and international researchers to share pertinent new and emerging scientific issues with GLERL, the University of Michigan, and to other universities and sites within the Great Lakes region.

- **CILER – GLERL Great Lakes Summer Fellows program:** CILER administers an annual Great Lakes Summer Student Fellows Program. This program demonstrates the strong partnership held between NOAA's GLERL and CILER that helps place promising young undergraduate and

graduate students with mentors of both the University of Michigan and federal research mentors. GLERL scientists mentor many students, which are summarized in the Service to Society Academic tab.

- 2015 – 15 fellows, of which GLERL scientists & communications staff mentored 9.
- 2014 – 12 fellows, of which GLERL scientists & communications staff mentored 9.
- 2013 – 10 fellows, of which GLERL scientists & communications staff mentored 9.
- 2012 – 13 fellows, of which GLERL scientists & communications staff mentored 10.
- 2011 – 15 fellows, of which GLERL scientists & communications staff mentored 7.
- 2010 – 13 fellows, of which GLERL scientists & communications staff mentored 9.

U.S. Geological Survey: Since 2010, GLERL has built on its relationship with U.S. Geological Survey in several ways.

- **Leadership Activities:**
  - National: Informal meetings and exchanges of information between GLERL and USGS laboratory and regional managers in Ann Arbor and Duluth, as well as with other USGS representatives from groups including the Coastal and Marine Geology Program laboratory in Massachusetts.
  - Local: U.S. Geological Survey – Great Lakes Science Center – located in Ann Arbor, Michigan
    - The GLERL deputy director served on a USGS search committee in 2012 for a new principal investigator.
    - GLERL hosted 2 USGS PIs and 6 Support staff during their lab renovations (duration of approximately 2 years)

- **Research Activities:**
  - GLERL PI served as co-science lead on USGS Invasive Mussel Collaborative.
  - GLERL PIs participated as part of the "Lower Food Web Working Group" with USGS, led by the Great Lakes Fishery Commission.
  - GLERL scientists strengthened or initiated new collaborations with USGS scientists, including through Coordinated Science and Monitoring Initiative (CSMI) projects in Lake Huron and Lake Michigan, and ongoing work with the USGS Center for Integrated Data Analysis in Wisconsin.
  - GLERL modelers partnered with USGS on assessing and improving the state of the art in regional hydrological modeling (GRIP-M).
  - GLERL PI, Tim Davis, collaborates with USGS Kansas Water Science Center on HAB ecology.
  - Tim Davis and Tom Johengen, Danna Palladino, Ashley Burtner, Rick Stumpf, Duane Gossiaux co-authored paper in the Special Issue of Harmful Algae.
  - GLERL scientists Henry Vanderploeg and Steve Pothoven each served as lead authors (with other GLERL and USGS scientists) on major papers on zooplankton dynamics in Great Lakes; there were a total of 7 other papers in which EcoDyn scientists were co-authors, e.g., H. Vanderploeg (GLERL), D. B. Bunnell (USGS), H.J. Carrick (CMU), and T.O. Hook (Perdue U.) were guest editors for Journal of Great Lakes Research 41 (Supplement 3) (2015) Special Issue "Complex interactions in Lake Michigan's rapidly changing Ecosystem".
  - GLERL collaborated on a funded project in with scientists at the USGS Great Lakes Science Center in Ann Arbor, on the effect of climate change on fish population and growth that resulted in the following papers:

- Kao, Y.-C., C. P. Madenjian, D. B. Bunnell, B. M. Lofgren, and M. Perroud, 2014: Temperature effects induced by climate change on the growth and consumption by salmonines in Lakes Michigan and Huron. Env. Biol. of Fishes, 98, 10.1007/s10641-014-0352-6.
- Kao, Y.-C., C. P. Madenjian, D. B. Bunnell, B. M. Lofgren, and M. Perroud, 2015: Potential effects of climate change on the growth of fishes from different thermal guilds in Lakes Michigan and Huron. J. Great Lakes Res., 41, 423-235, doi:10.1016/j.jglr.2015.03.012.

Industry: Since 2010, GLERL has built on its relationship with industry, as indicated below.

- The interaction of GLERL with the private sector has resulted in strong working relationships with LimnoTech on the Great Lakes Observing System (GLOS) Design Report, released in June 2011. This initiative has been followed by additional GLOS-related work. GLERL interactions with LimnoTech also led to the transition of buoy information into operation through GLOS.
- Through its Vessel Operations, GLERL supports the conversion of federal and other vessels to biofuel and biolubricants which has expanded to over 500 vessels. This work led to GLERL participation in a national feasibility study conducted in 2011 by the U.S. Army Corps of Engineers.
- GLERL participation in a Navy acoustics test of biofuel vessel power plants in 2012.
- GLERL management has initiated collaboration with faculty from the University of Michigan's Ross School of Business that will lead to an economic impact analysis of the laboratory and its research.
- Cooperative partnerships continue to be developed with Nortek, Fondriest Environmental, and SeaLandAire advancing real-time observation technology and high-resolution remote sensing in the Great Lakes region and at GLERL.
- Initiated forecasting improvements project with New York Power Authority and Ontario Power Generation to support operational decision-making at Niagara Falls and St. Lawrence River hydro power facilities
- Provide scientific expertise to the U.S. Nuclear Regulatory Commission on possible future water level scenarios
- GLERL works with Monterey Bay Aquarium Research Institute (MBARI) on the Environmental Sensor Processer (ESP) technology

4. Upgrade laboratory equipment and computing resources

Significant progress has been made since 2010 on the upgrade of laboratory equipment and computing resources. GLERL takes a lifecycle management approach to plan in the near and long term for new costs, and to identify emerging needs as well as obsolete equipment. To implement this approach, an internal process was developed at GLERL to prioritize capital equipment purchases, and priorities for the next several fiscal years have been identified by branch chiefs.

- To improve capabilities, and efficiency, GLERL purchased the following research equipment:
  - A top-of-the line Leica inverted microscope and image analysis system with capabilities for fluorescent, phase, bright-field, and DIC optics; this microscope will advance our phytoplankton work, particularly with harmful algal bloom cyanobacteria such as *Microcystis*.

- A digitally imaging flow cytometer (FlowCam) for automatically counting and measuring phytoplankton and other seston in the 3 µm to 1 mm range.
- A new nutrient autoanalyzer system, which will increase sample output by a factor of three compared to the old system.
- A refrigerated centrifuge that can spin down liter quantities of algae and seston.
- A Multiple Opening/Closing Net and Environmental Sensing System (MOCNESS) 1-m2 MOCNESS with laser strobe unit to improve spatial studies. The MOCNESS consists of 10 nets that can be opened and closed by control from in discrete depth zones as defined by depth or other environmental parameters (e.g., light, chlorophyll, temperature, depth) monitored by the net system.
- An Environmental Sample Processor (ESP) provides *in situ* collection and analysis of water samples. In the process of collecting water samples, this state-of-the-art instrument is designed to concentrate microorganisms or particles, and automate application of molecular probes to identify microorganisms and their genetic products. The ESP is the first of its kind on the Great Lakes and possibly the first being used in freshwater.
- A Digital PCR machine which provides genetic analysis of organisms in water samples.
- A -180 cryofreezer is used to cool samples to sub-zero temperatures to stop any enzymatic or chemical activity which might cause damage to the material under study.
- Two FluorProbes (*in situ* spectrofluorometer to identify algal classes), one for use on Lake Michigan and another for Lake Erie.

GLERL also has developed the capability to perform in-house testing of water samples for fecal indicator bacteria, in support of tributary and river plume modeling and forecasting efforts connected with beach health.

- The following computing resources have been upgraded by GLERL:
  - Installed three SGI computing clusters totaling 572 cores, major memory expansion, and server and software upgrades.
  - Installed 13TB (terabyte) Linux storage server and new backup system for Linux servers.
  - Implemented automated acquisition of Great Lakes MODIS and Radarsat2 satellite images on the new CW operations server.
  - Consolidated 27 discrete servers into 2 Virtual Machines.
  - Reconfigured the High Performance Computers (HPC) to use more open source software and increased through put.
  - Improved cybersecurity risk from 42% to 86%.
  - Obtained a trusted Internet connection for both Ann Arbor and the Lake Michigan Field Station in Muskegon.
  - Facilitated the use of CAC card authentication for Windows computers.
  - Upgraded to Windows 7 and office 2010 migration.
  - Secured operation of all Mac systems at OSX 10.7 or higher.
  - Completed LMFS Building #2 network wiring and server room set up.
  - Supported the setup of a new CoastWatch Server.

5. Strategically expand observation and research to other Great Lakes as they fit into mission goals.

NOAA's observational capacity in the Great Lakes and coastal ecosytems includes operational and developmental systems that provide an understanding of physical, biological, and chemical processes.

Since 2010, GLERL—in collaboration with partners—has expanded observational capacity and research projects throughout the Great Lakes region including connecting waterways.

- **Remote Sensing**
  - Great Lakes ice type classification algorithm – transferring to NOAA National Environmental Satellite, Data, and Information Service (NESDIS) to produce operationally for Great Lakes
  - Prototype: Great Lakes Color Producing Agent (CPA algorithm prototype)
  - Prototype: CoastWatch Great Lakes Scatterometer Wind and Ice Cover Products
  - Hyperspectral airborne flyovers for detection of cynobacteria (CILER)
  - Mobile platform Collaborations with Great Lakes Observing System (GLOS) & CILER IVER-2 Autonomous Underwater Vehicles, Slocum G2 Glider
- ***In Situ* Observing Capacity**
  - Observation gaps of the Real-Time Meteorological Observation Network Great Lakes Network addressed through collaboration with the National Weather Service (NWS). The southern Lake Michigan MET stations were used to transition technology to NWS Central and Eastern regions that greatly increased the number of nearshore observing nodes. The demo network was actually a catalyst for NWS expanding the Great Lakes coastal observation network.
  - Western Lake Erie Nutrient Monitoring capacity (continuous parameters: soluble reactive phosphorus, temperature, conductivity, chlorophyll, PC, turbidity, CDOM, dissolved oxygen) established. R2A (research to application) optical sensor data transitioned to Great Lakes Observing System HAB data portal in 2015.
  - Long-term goals of the Observing Systems and Advanced Technology branch include year-round and under-ice observations on all five Great Lakes.
  - Monitoring of seasonal dynamics of nutrients and chlorophyll in Lake Superior comparable with Lake Michigan through collaboration with Michigan Tech.
- **Modeling**
  - Forecasting of Invasive Species
    - Habitat suitability (Great Lakes Aquatic Habitat Framework)
    - Species distribution model
    - Individual-based model to simulate Asian carp impacts
    - Potential dispersal models of selected non-indigenous species (coupling hydrodynamics)
    - Food web model – Ecopath with Ecosim to model Asian carp impacts on all Great Lakes
  - Hydrodynamic modeling of the connecting waterways: Huron-Erie Corridor, Straits of Mackinac, Upper St. Lawrence Seaway, forecast model development for the Michigan-Huron Straits of Mackinac (an area not previously covered by observations and modeling conducted with deployment of ADCPs and drifters)
  - Arctic teleconnection patterns
  - Five-lake FVCOM-ice model was implemented and refined for the entire Great Lakes to investigate seasonal and interannual variability, which will be transferred to nowcast/forecast system for NOS, and seasonal projection of lake ice cover at GLERL.
  - Partnership with colleagues from Canada to improve hydrological modeling in the Lake Ontario basin (through GRIP-O project).
  - The Ecosystem Dynamics branch initiated a seasonal long-term research program on Lake Huron, much like GLERL's program on Lake Michigan, made possible by leveraging external funding from the Lake Huron CSMI program in addition to base funds

- **Infrastructure:** GLERL Lake Michigan Field Station expanded the number of ports for docking GLERL vessels to increase our field research capacity, adding transient and full season vessel bases.
    - Added transient vessel bases in the following ports: Houghton, MI (Lake Superior); Milwaukee, WI (Western Lake Michigan); Traverse City (Grand Traverse Bay, northern Lake Michigan); Cheboygan, MI (Mackinac Straits connecting Lakes Michigan-Huron)
    - Expanded full season vessel bases to include: Alpena, Bay City (Lake Huron), Monroe, Cleveland, Lake Erie
    - Updated/expanded vessel fleet to meet scientific needs:
        - two 55 ' vessels expanded geographic and support for the following: HABs, ReCON, GLOS, event response.
        - one 50' vessel added new technologies to support GLERL research, including multi-beam, side scan sonar, dive support, onboard survey processing (Lake Huron).

6. Develop observing systems for year round and extreme environment application.

While there has been some focus on the objective to develop observing systems for year round and extreme environment application, some other more pressing Great Lakes issues have taken priority, namely, nutrient monitoring and HABs observations. However, plans are underway to focus more resources on this objective for the coming year. One such project is the development of two cabled buoy systems with plans for deployment this summer. In addition, a proposal with GLOS has been submitted for four more year-round stations.

Long-term goals of the Observing Systems and Advanced Technology branch include direct or collaborative year-round and under-ice observations on all five Great Lakes. In the winter of 2012-2013, GLERL kept its largest research vessel operational throughout the winter to facilitate sampling in December and January. Over the winters of 2010-2011 and 2011-2012, GLERL scientists collaborated on deployment of acoustic doppler current profilers (ADCPs) in Lake Erie to study ice formation and thickness.

CILER-supported AUVs have also expanded GLERL's environmental measurement capabilities and expanded collaborations on aircraft and satellite remote sensing with NASA, Environment Canada, and the Canadian Coast Guard are also underway.

Currently, GLERL has five, year-round, offshore, real-time observing stations deployed on navigations structures:

1) Stannard Rock – Middle of Lake Superior
2) White Shoal - Northern Lake Michigan
3) Spectacle Reef – Lake Huron
4) Toledo channel marker #2 – Lake Erie
5) Chicago Water Intake

GLERL has been providing a leadership role in collecting and transmitting data from these unique offshore platforms in partnership with Environment Canada, University of Colorado - Boulder, Limnotech, GLOS and the University of Toledo. Also, as part of its research on extreme environments, GLERL deployed high-resolution water level sensors in coastal areas to detect meteotsunamis.

7. Develop detailed design/construction/maintenance plans for current systems and for future expansion plans

Existing design/build documentation will be augmented with operations and maintenance procedures, keeping technology transition in mind, especially with systems such as Real-time Environmental Coastal Observation Network (RECON). One example of an integrated system design effort that GLERL has spearheaded was the 2011 report, *Near-Term Design of the Great Lakes Observing System Enterprise Architecture* by LimnoTech (http://www.limno.com/pdfs/GLOSEA_Exec_Summ_091511.pdf). This effort has been highlighted by the leadership of the national Integrated Ocean Observing System (IOOS) program as a model for other regions in the country.

These improvements in instrumentation have led to the development of nutrient monitoring buoys, improved existing ReCON buoys, and allowed expansion to year-round under-ice systems.

Progress is also being made to improve GLERL's infrastructure. At the Lake Michigan Field Station, Building 2 was completely renovated. In addition, plans are underway to assess and design the LMFS Building 3, allowing for the science laboratories to be consolidated within one building, in complete compliance with safety regulations. The reconstruction of Building 3 will provide increased capacity for laboratory facilities needed to conduct process experiments that must be done with "fresh" organisms sampled directly from the field. This building project also plans to provide additional space for visiting scientists working with the EcoDyn group on priority issues.

A priority goal for GLERL's Vessel Operations is to establish a comprehensive, long-range plan facilitating innovative and effective (uninterrupted) vessel service in support of GLERL science. As part of this effort, the Vessel Operations team is in the process of completing a long-term needs assessment on the small research vessel (SRV) platform that includes identifying supporting partners, funding mechanisms and operational structure. In addition, a NOAA Great Lakes regional fleet panel is being established with qualified representatives to assess future vessel needs in the Great Lakes.

8. Plan for publication in* Science *or* Nature *every few years to boost deserved recognition.

GLERL authors have recently published papers in both *Science* and the *Proceedings of the National Academy of Sciences*, with respective impact factors of 33.6 and 9.7. Additionally, we continue to publish in top journals within the field including:

- *Frontiers in Ecology and the Environment* (impact factor = 7.4)
- *Water Research* (impact factor = 5.5)
- *BioScience* (impact factor = 5.5)
- *Environmental Science & Technology* (impact factor = 5.3)
- *Geophysical Research Letters* (impact factor = 4.2)
- *Limnology & Oceanography* (impact factor = 3.8)
- *Water Resources Research* (impact factor = 3.5)
- *Journal of Geophysical Research* (impact factor = 3.4)

Publication without calculated impact factor:
EOS: 2015 GRONEWOLD, A.D., A.H. CLITES, J. Bruxer, K.A. Kompoltowicz, J.P. SMITH, T.S. HUNTER, and C. Wong. Water levels surge on the Great Lakes. Eos 96(6):7 pp. (2015). https://eos.org/project-updates/water-levels-surge-on-great-lakes

It should be noted that a number of papers appearing in special issues of the Journal of Great Lakes Research as well as other journals have been highly cited, therefore reaching an international audience beyond the Great Lakes.

Special Issues:

- 2016 Harmful Algae Special Issue: Harmful Algae Global Expansion of Harmful Cyanobacterial Blooms: Diversity, Ecology, Causes, and Controls (April 2016). Guest Editors: Timothy Davis and Christopher Gobler.
- 2015 Journal of Great Lakes Research Special Issue: Complex Interactions in Lake Michigan's Rapidly Changing Ecosystem (22 papers address direct and indirect impacts of nonindigenous species on the Lake Michigan ecosystem). Guest Editors: Henry A. Vanderploeg, David "Bo" Bunnell, Hunter J. Carrick and Tomas O. Höök.
- 2014 Journal of Great Lakes Research Special Issue: The Continuing Effects of Multiple Stressors in Saginaw Bay, Lake Huron (21 papers, 7 with GLERL first authors). Guest editor: Craig Stow
- 2013 Journal of Great Lakes Research Special Issue: Remote Sensing of the Great Lakes and other Inland Waters (19 papers). Guest Editors: Robert Shuchman and George Leshkevich.
- 2012 Journal of Great Lakes Research Special Issue: The Lower Food Web of Lake Michigan: Long-term trends and the Dreissenid Impact. Guest Editor: Henry Vanderploeg.

Sample of Web of Science High Impact Publications (for a complete listing see review web site) http://www/review2016/supporting_documents.html

- Harke, M.J., T.W. DAVIS, S.B. Watson, and C.J. Gobler. Nutrient-controlled niche differentiation of western Lake Erie cyanobacterial populations revealed via metatranscriptomic surveys. Environmental Science & Technology (2016).
- DAVIS, T.W., G.S. Bullerjahn, T. Tuttle, R.M. McKay, and S.B. Watson. Effects of increasing nitrogen and phosphorus concentrations on phytoplankton community growth and toxicity during Planktothrix blooms in Sandusky Bay, Lake Erie. Environmental Science & Technology 49:7197-7207 (2015). http://www.glerl.noaa.gov/pubs/fulltext/2015/20150039.pdf
- DAVIS, T.W., S.B. Watson, M.J. Rozmarynowycz, J.J.H. Ciborowski, R.M. McKay, and G.S. Bullerjahn. Phylogenies of microcystin-producing cyanobacteria in the lower Laurentian Great Lakes suggest extensive genetic connectivity. PLOS One 9(9):9 pp. (DOI:10.1371/journal.pone.0106093) (2014). http://www.glerl.noaa.gov/pubs/fulltext/2014/20140048.pdf

9. Develop and implement adaptive sampling programs that integrate new statistical sampling designs and new technologies.

- GLERL purchased a Multiple Opening-Closing Net with Environmental Sensing System (MOCNESS) (for MOCNESS description, see recommendation 4) that will improve pelagic food web sampling). New fish acoustics instrumentation was installed on the *R/V Laurentian* (during a dry dock overhaul in 2012) that permits collection of continuous acoustical data relevant to

upper food web structure. In addition flow-through sampling systems will be installed on GLERL vessels to facilitate in-route sampling during transits and surveys.

- The use of multiple technologies (i.e., Plankton Survey System, acoustics, MOCNESS) has allowed GLERL to push boundaries in sampling all components of the food web—from microbes to fishes—simultaneously, at fine spatial scale in vertical and horizontal dimensions, and both day and night. Collaboration with university colleagues has allowed the sampling of microbial food web components. The "microbes to fishes" spatial cruises are now a standard part of GLERL's sampling strategy in Lake Michigan with seasonal cruises done in April, July, and September. In 2015, as part of GLERL's contribution to the Coordination Science and Monitoring Initiative (CSMI), this multi-faceted sampling approach was used from April –October to provide a unique data set on spatial structure of the food web in Lake Michigan during all seasons. On these same cruises our academic partners sampled spatial distribution and function of the microbial food web using both microscopic and genetic tools. GLERL's work was a compliment to the sampling conducted by other agency partners at less frequent and coarser scales at several locations throughout the lake.
- GLERL is also broadening Environmental Sample Processor (ESP) Genomics methods to study harmful algal blooms (HABs) and has brought in molecular tools to identify harmful algae and microbes, looking at full the spectrum from genetics – satellites, in collaboration with partners. Currently, GLERL is in collaboration with CILER and GLOS on propelled and gliding AUVs.
- GLERL's modelers are participating in the increased sophistication of statistical sampling design that is being realized by better integration of iterative modeling efforts, field monitoring, and experiments. An example is the expansion of monitoring of the deep thermal structure of the lakes from Lake Michigan to Lake Huron in 2011. This research has been driven by model validation requirements, and expansion of over-lake evaporation measurements via upgrading and expansion of eddy correlation stations on fixed mid-lake platforms.
- Coordinated, synchronous, multi-platform monitoring and experiments were performed in lakes Erie, Huron, and Michigan.
- Rapid-response sampling linked to an anomalous satellite-detected spring bloom in Lake Erie, and storm events in a Lake St. Clair tributary were performed.
    - Hyperspectral overflights during the summer of 2015 have shown the potential to provide HABs observations under clouds when satellite imagery is unavailable.
    - GLERL has worked on differentiating sources of water quality variability using novel Bayesian statistical methods.
    - GLERL has also explored spatiotemporal variability of near-shore pollutant to determine optimum sampling sites.

10. Develop a more comprehensive conceptual and methodological approach to the food web that can reasonably be expected to detect the presence and impact of new species.

This research need is a primary driver for the development of an Integrated Ecological Modeling Framework. GLERL is working toward meeting this need through modeling of multi-decadal impacts on food webs of Asian carp introductions to parts of the Great Lakes. GLERL is also expanding larval fish sampling and modeling capabilities by hiring contract technicians and acquiring a MOCNESS, in addition to other field and lab upgrades. The hiring of two ecologists and the retention of current postdoctoral fellows holding this expertise, have significantly helped these efforts.

Through the LTR on Lake Michigan, GLERL conducts a high frequency (bi-weekly) analysis of samples soon after collection with report-out within a few months of the end of field season, allowing for the potential for invasive species to be detected sooner. The status of the food web is reported in March, following the end of the field season.

11. Expand and develop research in mission critical areas such as biogeochemistry, food web dynamics, and integrated bio-physical and ecosystem modeling.

The implementation strategy of the 2012 strategic plan outlined the additional staff positions that would be required for GLERL to retain its position as a leader in food web dynamics and to strengthen its capabilities in bio-physical modeling. These research needs are also primary drivers for the development of an Integrated Ecological Modeling Framework at NOAA, in which GLERL serves in a leadership role.

At this time, resource limitations have dictated that biogeochemical research at GLERL will primarily be conducted through numerical modeling rather than field work, laboratory analyses, and experimentation. Active collaborations have continued in this area through CILER and efforts such as the National Science Foundation (NSF)-supported effort on Biogeochemistry of the Great Lakes System (BOGLS). GLERL contributed financially to this project and a GLERL scientist was a co-principal investigator on the proposal for a 2013 science-planning workshop partially funded by the NSF Chemical Oceanography program, along with other federal agencies and universities.

A biophysical modeler, supported by GLERL through the NRC Research Associateship Program and CILER, has made important progress on the impact of invasive mussels on the Lake Michigan ecosystem, using sophisticated spatial analysis and coupled biological and hydrodynamic models. This has allowed projection work from experiments and field observations done at GLERL to impact at the whole ecosystem level. GLERL is in the beginning stages of the hiring process for a biophysical modeler. Likewise, work is underway on biophysical models on HABs and hypoxia distributions in Lake Erie. GLERL is planning to expand NOAA HAB forecasting tools to Green Bay and Saginaw Bay within the next few years.

Other examples of projects that meet this recommendation:

- HAB forecast model Lake Erie; Hypoxia forecast
- Bio-physical Lake Michigan mussel dynamics
- Real time P monitoring in Saginaw Bay

12. Better communication is necessary within and between the theme programs on the development and implementation of mission goals.

This recommendation has been a primary focus of lab management and branch chiefs since the 2011 reorganization of GLERL into three science theme branches. Through the standing forum of monthly Science Council meetings, all decisions related to science are presently made in conjunction with all branches during the annual project planning process. The integrated Science Strategy in the 2012 strategic plan outlined how the science branches work on both an independent level and collectively to fulfill GLERL's mission and address specific science goals. In the 2012 strategic plan, science goals were developed with participation from all science branches, also driven by internal resource allocations and

external commitments (e.g., project budgets, staffing, vessel time, major equipment purchases, external proposal submissions).

A key change in GLERL's organizational structure made in response to the identified need for improved cross-branch communication is the formal establishment of the Information Services (IS) Branch. The IS branch operates in conjunction with GLERL's three science branches to maintain strong communication among the branches and to ensure that the scientists hold a common understanding of administrative and operational developments at GLERL. In addition to OAR's Hot Items used to inform NOAA leadership on GLERL's scientific and related management developments, the IS branch is leading new initiatives to improve communication and engagement among GLERL staff, such as the GLERL Newsletter and the internal GLERL brown bag series.

A GLERL PI Retreat was held in 2011 to ensure the director's office and principal investigators develop a collective understanding of the current state of GLERL's research portfolio and build consensus on the primary future research directions of the laboratory. Outcomes from the retreat have also guided the director's office in planning higher-level institutional visits, in efforts to establish natural alignments and coordinate on activities and initiatives of common interest. Such visits include: NOAA headquarter program offices, Pacific Marine Environmental Laboratory, Chanhassen Office, Ecological Forecasting Roadmap Team, Grand Valley State University-Annis Water Research Institute, Great Lakes Sea Grant Network; the U.S. Army Corps of Engineers (USACE); Environment Canada; Great Lakes Governors Association; Northeast-Midwest Institute (NEMWI); NASA ; St. Clair Detroit River System (formerly known as the Huron-Erie Corridor (HEC)); UW-Milwaukee.

The application of a cross-branch, cross-line, and cross-agency approach is well demonstrated by GLERL's longstanding research program on harmful algal blooms (HABs) in the western basin of Lake Erie and Saginaw Bay. The primary ecological problem under investigation is the extent, duration and toxicity of HABs in response to human-induced stressors, thus impacting the water quality of Lake Erie's western basin and other regions of the Great Lakes. The HABs research program at GLERL is conducted with participation from all of GLERL's four branches and in collaboration CILER and NOAA's National Centers for Coastal Ocean Science (NCCOS). In addition, the HABs project demonstrates an adaptive integrated research approach.

The SOAR project—another exemplary cross-branch project—is built upon external collaborations utilizing the Marine Instrumentation Lab, Western Lake Erie sampling and Satellite Measurements, and model output from the HAB Trackers. Another example of cross-branch research is the work being conducted on model coupling hydrology – hydrodynamic – atmospheric components for forecasting.

Moving forward, the recently completed strategic plan 2016-20120 has been developed through a highly interactive process over several months to engage staff in the process of consensus building on the plan's goals and metrics. An important outcome of this process is the establishing a common understanding and facilitating communication across GLERL's theme groups.

13. Attention to the progress of Jorg Imerger and Jason Antenucci of CWR at the University of Western Australia in terms of coupling biogeochemical and physical models.

GLERL scientists interact with CWR scientists at international conferences such as the International Society of Limnology and Physical Processes in Natural Waters.

14. Continue to develop the increasingly important connection to NOAA's National Ocean Service (NOS) (including the Coast Survey Development Laboratory (CSDL) and Center for Operational Oceanographic Products and Services (CO-OPS)).

- GLERL has established connections with the U.S. Integrated Ocean Observing System, the National Data Buoy Center, and CO-OPS, which continue to evolve. GLERL management met with NOS leadership in Ann Arbor and at NOAA headquarters in 2011 and 2012 to build on this relationship, and successfully advocated for establishment of a permanent position in GLERL's Ann Arbor facility for a National Ocean Science (NOS)-National Centers for Coastal Ocean Science scientist with the regional Ecosystems Research Branch.
- GLERL management, the GLERL hydrology research group, and those associated with the Great Lakes Observing Systems (GLOS) design project have had ongoing interaction with CO-OPS, including participation in workshops and other activities.
- The GLERL vessel operations group has worked with the NOS lab in Oxford, Maryland to secure a replacement for their research vessel destroyed in a fire, and is currently refurbishing the vessel in Michigan.
- GLERL continues to participate in initiatives that build on the partnership with NOS, particularly with the Line Office's research programs and in joint Ecological Forecasting and Habitat Blueprint activities. Examples include:
- GLERL hosted a visit with NOS leadership, including Mary Erickson, Director of the National Center for Coastal Ocean Science (NCCOS); Richard Edwing, Director of the CO-OPS; and Jeff King, Acting Director of the Hollings Marine Laboratory. Discussions were held during their visit in areas of ongoing collaborations as well as current and future connections to help advance ecosystem modeling and forecasting. Potential areas of collaboration involve the following:
    - Planned transition of the new Lake Erie hydrodynamic model (and eventually others).
    - Planned transition of the Lake Erie HAB forecast
    - Upcoming International Great Lakes Datum (IGLD)
- The 2015 HAB forecast based on an ensemble modeling approach that integrates precipitation, river flow, and nutrient run-off measurements to predict the Lake Erie HAB. In conjunction with GLERL scientists, the models were developed by scientists at NOAA's NCCOS, CILER, LimnoTech, University of Michigan (U-M), and North Carolina State University. The ensemble approach was used for the first time in the 2015 forecast to increase accuracy and provide improved tools for resource and state managers working on HABs related problems.
- The Great Lakes Subgroup of the Harmful Algal Bloom and Hypoxia Research and Control Act (HABHRCA) Interagency Working Group (IWG) is co-led by NOAA and U.S. Environmental Protection Agency researchers. The primary objective of the HABHRCA Great Lakes Subgroup, led by GLERL's Tim Davis, is to develop a research plan and action strategy addressing harmful algal blooms (HABs) and hypoxia issues in the Great Lakes—mandated under the recently passed HABHRCA legislation. Integral to this initiative is the support provided by the 2015 Sea Grant Knauss Fellow, Dr. Linda Novitski, was co-located at GLERL and at the NOS Silver Spring office. In this role, Dr. Novitski worked in close concert with Tim Davis (GLERL) and NCCOS Director and IWG Co-Chair, Mary Erickson, helping to bring a Great Lakes perspective to NOAA

Headquarters. The national report, "HABs and Hypoxia: An Interagency Research Plan and Action Strategy," includes a Great Lakes Integrated Assessment which outlines current federal agency efforts to mitigate harmful algal blooms and hypoxia. The current IWG-HABHRCA report is focused entirely on the Great Lakes, and lays out the challenges and recommendations for implementation of effective and coordinated HABHRCA efforts.

- GLERL continues a strong relationship with NOS/CSDL transition of next generation GLOFS (Great Lakes Operating Forecasting System) to NOS/CO-OPS. GLERL initiated joint NOS – GLERL teleconferences on a monthly basis focusing on water level status and messaging, as well as transitioning next generation GLOFS model and HAB Tracker to NOS as part of NOS five-year plan. In addition, NOS and GLERL continue their strong relationship through contributions to the Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data. Through this established relationship, plans and a pathway have been developed to transfer lake models. GLERL, CSDL and CO-OPs held weekly conference calls to discuss transition progress, held model advisory board meetings every quarter to set transition milestones and have in-person meetings twice a year in Silver Spring on model development. The Lake Erie model transfer will be complete in April 2016.
- Additional examples of engagement with CSDL and NOS:
  - Selection of Dr. Philip Chu as IPEMF Branch Chief.
  - GLERL's newly-appointed Deputy Director holds experience in NOS and NWS.
  - Coordinated the deployment of Great Lakes water lever viewer (NOS product) with Great Lakes water level dashboard (GLERL product).
  - New collaboration with Greg Doucette – Charleston laboratory on ESP toxin essay.

15. Continue to develop and communicate complex model forecast results and uncertainty in critical areas related to human health and safety.

GLERL's Integrated Physical and Ecological Modeling and Forecasting branch continues to develop integrated environmental modeling systems and seeks new ways to communicate complex model forecast results and model uncertainty in partnership with others, including U.S. EPA program managers, USGS scientists, NWS researchers, Sea Grant program managers and grantees, and the GLERL Information Services branch.

The commitment to addressing uncertainty in scientific research is well demonstrated by the GLERL-hosted workshop held on modeling uncertainty in April 2015. Outcomes from the workshop are presented in the document: *Report from the Joint OAR-NMFS Modeling Uncertainty Workshop. NOAA Technical Memorandum NMFS-F/SPO-153,* authored by Link, J., D. Mason, T. Lederhouse, S. Gaichas, T. Hartley, J. Ianelli, R. Methot, C. Stock, C. Stow, and H. Townsend. 2015.

As noted above, a number of biophysical models to develop ecosystem forecasts are under development for Lake Michigan and Lake Erie in the following critical areas: harmful algal blooms, hypoxia, water quality, and food web dynamics, Another example of current work in this area is a study using Bayesian statistical models to quantify uncertainty in fecal indicator bacteria measurements, which was completed in FY2011 and has been incorporated into forecast models in FY2012. GLERL also began a field sampling program for fecal indicators to improve modeling approaches on a Great Lakes tributary, the Clinton River, in 2012. Bayesian-based models were also developed to predict total phosphorus, chlorophyll a, microcystin, and their uncertainty for Saginaw Bay.

The attention that GLERL focuses on uncertainty is also exemplified by the Center for Sponsored Coastal Ocean Research (CSCOR) Workshop: Quantifying Uncertainty of Asian Carp Impacts on Great Lakes Food Web and Fisheries. GLERL and CILER scientists participating on this project include Edward Rutherford, Hongyan Zhang, Lori Ivan, Doran Mason, along with many partners from non-profits, state and federal agencies and universities. Three different models are used in this project to simulate the impacts of Asian carps (and other new invasive species) on Great Lakes food webs and fisheries.

Other uncertainty related projects conducted at GLERL include:

- Development of innovative web-based graphical user interfaces i.e., dashboard product, to communicate uncertainty within and variability between complex climatological and hydrological forecast systems.
- The Ecopath with Ecosim model for Lake Erie now incorporating uncertainty and links to economic models.